Downtonian Strata.

Above the horizon of the Aymestry Limestone, which forms the divisional line between the Lower and Upper Ludlow groups of Murchison, no distinct species of Graptolite has yet been identified. Prof. Phillips * notices the presence of Graptolites in the Upper Ludlow of the Malvern Hills, but does not attempt their identification. Mr. R. Etheridge † catalogues a fragment of a Graptolite from the supposed Lower Old Red Sandstone of Lanarkshire. Mr. G. Linnarsson informs me that he has recently recognized a Graptolite in a collection of fossils from the Gothland Sandstone, which possibly corresponds to the lower part of the British Downtonian series.

[To be continued.]

VI.—*On the Action of Light and the Function of Chlorophyll in Plants.* By M. Pringsheim ‡.

My purpose in this preliminary communication is to state some results which I have obtained by a new and peculiar method of investigation in *concentrated sunlight.*

I have made use of this method for some years in order to gather experimental knowledge of the relations of light to the absorption of gases by growing plants, and of the part played therein by chlorophyll. Amid the confusion of contradictory opinions and statements which pervade the literature of the subject, after many vain endeavours to advance upon the path usually trodden, I felt myself bidden to proceed to the employment of *intensified light.* I hoped thus to be able in a short time to bring into view, and unequivocally to observe immediately in the cell, and directly under the microscope, the processes called forth in plants by the action of light.

In fact the experiments which have hitherto been made have laboured under the serious defect that too inconsiderable intensities of light were employed. This is especially true of those experiments in which it was endeavoured to prove that the different colours of the spectrum act differently upon plants. If plants are grown in diffused daylight, or even in direct sunshine behind coloured screens or coloured glasses or

* Phillips, Mem. Geolog. Survey, vol. ii.

† Etheridge, Mem. Geol. Survey Scotland, Explan. Sheet 23, p. 57.

‡ Translated from the 'Monatsbericht der königlich preussischen Akademie der Wissenschaften zu Berlin,' July 1879, pp. 532–546.

liquids, they evidently grow in relative obscurity in comparison with their normal conditions, even in relation to the colour the action of which is wished to be investigated ; hence the results thus obtained correspond only to the actions produced in plants by *insufficient* intensities of light. Moreover the function of chlorophyll itself contributes to the weakening of the result. I mention this because certain conjectures respecting the function of chlorophyll, which have since been verified, first induced me to take up these experiments with higher intensities of light.

So long as I employed only comparatively inconsiderable augmentations of the intensity, I obtained no decisive results. I at last attained satisfactory effects when I ventured to bring organic forms, vegetable and animal cells and tissues, into the plane of an image of the sun which I projected in the focus of an achromatic lens of 60 millims. diameter.

The apprehension which perhaps at first arises, that organic structures must under these circumstances be forthwith destroyed by the thermal action of the solar image, is, as a closer consideration and direct experiment show, unfounded. With proper precautions, the object can be observed undisturbed for a considerable time in the sun's image, as indeed is approximately shown by the phenomena in the so-called solar microscope. In this way the influence of the radiation upon an entire tissue and upon *each single cell*, nay, even upon *the different form-constituents of a single cell*, can be *separately* studied, and with a little attention the thermal and photochemical effects of the radiation can be certainly and sharply distinguished.

Hence this method of *microscopical photochemistry* (as I would call it) is preeminently adapted for investigating whether any, and what, photochemical actions of light take place in protoplasm and in the formed constituents of the cell-body ; and it is equally suitable for determining the relative degree of diathermasy of the cell-contents and the cell-membrane. In this way also the effects of higher degrees of heat can be more conveniently brought into view than by aid of heated object-tables. Lastly, it is self-evident that the method is applicable for animals and animal tissues as well as for plants ; and with it we can at the same time demonstrate the sensation of heat in the lowest classes of animals (Protozoa and Cœlenterata), and in certain cases ascertain the truth respecting the presence, and the seat, of the perception of light.

The experiments in reference to this which, in the course of my investigations, I have made on animals I will communicate subsequently; I will here preliminarily enter more minutely only into that part of my researches which has for its subject the influence of light upon the plant-cell.

If a chlorophyll-bearing tissue, or even a single cell containing chlorophyll (a moss-leaf, a fern-prothallium, a *Chara*, a *Conferva*, or a section of a leaf of any Phanerogamic water- or land-plant &c.), be placed in the usual manner under the microscope, while, at the same time, by means of a heliostat and a lens of about 60 millims. diameter, the image of the sun is thrown upon the plane of the field of vision at the spot in which the object is, so that the latter appears formally immersed in the image, in a few minutes (from 3 to 6 and upwards) very considerable and energetic changes can be seen to take place in the object.

The first phenomenon seen, more striking than any other, is the *complete destruction* of the chlorophyll under the eye of the observer. The green plant-cell, exposed only a few minutes to the concentrated sunlight, makes exactly the same impression as if it had lain for twenty-four hours in strong alcohol. The green colouring-matter has disappeared, while the primitive substance of the chlorophyll has for the most part its forms entirely preserved, and even its nature apparently not essentially altered. But in the experiments in the light it will be possible to localize the decolorization, and at pleasure to confine it to a single cell or even a portion of a cell; for the destruction strikes only the place upon which the light is directly incident; so that, for instance, in a cell a single chlorophyll-grain, a single turn of a filament in a *Spirogyra*, &c. are decolorized, while the adjacent grains of chlorophyll and the next preceding and following coils remain intact in form and colour.

The changes which take place, however, are not limited to the destruction of the green colouring-matter only; they *gradually attack also the other constituents of the cell*, and, according to the duration of the action of the light, go on to the complete death of the entire cell. Thus, if its duration is protracted, the motion of the granules in threads of protoplasm, and the circulation of the protoplasm itself, where they previously existed (as in the utricles of *Nitellæ* and *Charæ*, in the leaf-cells of *Vallisneria*, in the hairs of the staminal filaments of *Tradescantia*, in the stinging hairs of *Urtica*, &c.), are arrested; the threads of protoplasm break; the normal arrangement of the cell-contents is destroyed; the cytoblast, where it occupies certain positions (as in the *Spirogyræ*), is dislocated, breaks away from the threads of protoplasm to which it is suspended; the cuticular layer contracts, loses its impermeability to colouring-matters; the turgescence of the cell is annihilated; in short, the cell exhibits all the phenomena of rapid and irreparable destruction.

These phenomena are *not* direct effects of a high temperature produced in the cell by the radiation. By varying the experiment by means of coloured screens, causing the rays which delineate the image of the sun to pass through coloured glasses or vessels containing coloured fluids, this can be rendered highly probable, as I will show in my detailed presentation of the subject. I will here merely mention that the destruction of the contents of the cell in the way above portrayed takes effect in *all colours*. It matters not whether the image of the sun is produced as a *warm red* image behind a solution of iodine in sulphide of carbon, or as a *green* one behind a solution of chloride of copper, or as a *cold blue* one behind ammonio-cupric sulphate; the result is always the same, provided only that the coloured screens transmit a light of *sufficient* intensity.

It is, however, easily perceptible, even without photometric measurement, that *blue* light exerts a more powerful action than *red*. Behind a solution of iodine in sulphide of carbon so concentrated that, except the red up to the wave-length 0·00061 millim., to the human eye it transmits no portion of the spectrum, especially no blue, even in direct sunlight, the phenomena described will *not* be seen to occur even with long-continued action of the sun's image, although here at least 80 per cent. of the total heat of the white image is effective, and although this red image still possesses a brightness unendurable even for a very short time by any human eye, and, finally, although the first two strong absorption-bands of the chlorophyll-spectrum fall in the red of this image of the sun, and consequently this red is absorbed in considerable quantity by the chlorophyll.

On the other hand, a rapid and powerful action always takes place behind even a *dark* solution of ammonio-cupric sulphate, which absorbs the entire less-refrangible half of the solar spectrum to about the wave-length 0·00051 millim., and likewise behind a screen of deep-green glass, which is but very slightly diathermanous.

But, apart from the action being independent of the greater or less diathermasy of the screen, the most direct proof can be adduced that the destruction wrought in the cell does not depend upon the thermal action of the radiation; for it can be shown that the occurrence of all the phenomena of destruction of the cell and its contents in the light is exclusively conditioned by the presence of oxygen in the surrounding atmosphere.

The destruction does not take place in media free from oxygen.

If the experiments be made in a so-called microscopic gas-chamber, through which various gases can be passed during the experiment, the effects above described take place only in atmospheric air and in media containing oxygen; but they constantly fail to appear, under otherwise like conditions, even if the experiment be continued twice or three times as long, in hydrogen or media containing no oxygen. But both when atmospheric air passes through the gas-chamber, and when oxygen is substituted for the air, the absorptions of the chlorophyll remain unaltered, and the thermal actions of the sun's image at least equal. If, however, the experiment be *excessively prolonged* in hydrogen, disturbances, it is true, will be seen to occur; but these, even in their first stages, are essentially different from those described, and are easily shown to be thermal effects.

Even in a *mixture of pure hydrogen and carbonic acid* cleared as much as possible of free oxygen, under these circumstances neither in any colour nor in white itself does any photochemical action appear: the green cell remains therein perfectly green and in every respect underanged.

On the other hand, the *abstraction of the carbonic acid* has not the slightest influence upon the occurrence of the action. In air containing oxygen, from which by all possible means the carbonic acid is abstracted before it enters the gas-chamber, the decolorizing of chlorophyll, the destruction and death of the cell take place as rapidly as in media containing carbonic acid.

The conclusions to be drawn from these experiments are clear and simple.

If we in the first place stop at the action of the light upon the green colouring-matter, we find in the demonstrable dependence of the phenomenon upon the presence of oxygen, and in its independence of the abstraction of carbonic acid, proof that *the destruction of chlorophyll by light in the living plant is an act of combustion influenced and promoted by the light, and stands in no relation to the decomposition of carbonic acid by the plant.*

By varying the experiment, *e. g.* shortening its duration by stopping the action before *complete destruction* of the colouring-matter in the chlorophyll-bodies, it can further be shown that the cell and, in like manner, the individual chlorophyll-grain are incapable of restoring the destroyed colouring-matter of the partly decolorized chlorophyll-bodies, although with so brief a duration of the action of the light the cell behaves in all other respects quite normally, remains living, and may even continue to grow.

This incapacity of the cell, and of every single chlorophyll-grain, to regenerate the colouring-matter destroyed by light holds good for all, even *the least, degrees* of weakening or destruction of colour in the chlorophyll-grain. It hence follows that the destruction of chlorophyll by light *cannot be a normal, physiological act* in the life of the plant, but is a detrimental and pathological process.

What becomes of the chlorophyll colouring-matter on its destruction by light in the cell I could not make out, although I took much pains for the purpose of doing so. I did not succeed in a microchemical way in discovering any substance, in the cell decolorized by light, which could be regarded as the product of the destruction of the chlorophyll. A possible simultaneous augmentation of the oil or the starch of the decolorized cell, or the formation of grape-sugar or dextrine, cannot be ascertained. Hence I am inclined, so far as my investigations have yet extended, to assume that herein the chlorophyll passes direct into the gaseous products of the respiration of the plant.

With respect to the rest of the above-sketched destruction-phenomena, which occur with these experiments in intensified light *in the protoplasm and the not green contents of the cell*, and which can be heightened to the death of the cell, there is no doubt that they too are *direct* photochemical actions of light. They are *not* immediate thermal effects of the sun's image; nor are they *secondary* phenomena produced, as might perhaps be thought, by some yet unknown poisonous products of the destruction of the chlorophyll colouring-matter in light. This is proved, first, by experiment on cells which are colourless and contain no chlorophyll—as, for example, on the hairs of the filaments of *Tradescantia*, on the stinging-hairs of *Urtica*, &c., in which the arrest of the motion in the threads of protoplasm and their destruction in light occur in a similar manner and under the same circumstances as in green cells and is promoted by the presence of oxygen.

A sufficiently rigorous demonstration can moreover be obtained with *green* cells and tissues, if, in the way above mentioned, we shorten the duration of the experiment, breaking it off *after* the destruction of the chlorophyll and *before* the cell-contents beneath this have suffered under the action of the light. Singularly favourable for experiments of this kind are the long utricles of *Nitella*. If a small fraction of the length of one of these be exposed to the influence of light, and the experiment be stopped when the chlorophyll is deprived of colour but the motion of the protoplasm in the utricle is still maintained, this will continue living for days and weeks and behave quite like a normal, uninjured utricle.

Frequently the decolorized chlorophyll-bodies, if the experiment has been stopped at the right time, then fall down from the wall of the utricle into the level of the current, are carried along and circulate with it uninterruptedly, and without being altered, in the regular path of its flow, and travel the whole extent of the path through the entire utricle with the same velocity as the other large formed bodies contained in it (the mucilaginous and ciliated corpuscles), without further disturbing the course of the current.

The place on which the light has fallen, however, appears completely bare, and, denuded of chlorophyll-bodies, lets the underlying cell-contents be directly seen. At the same time the wall-coating of the green parts of the utricle may remain quite unaltered and exhibit, for instance, the chlorophyll-bodies, the arrangement of the chlorophyll series, the indifference-streaks, &c. in normal condition quite as usual. These utricles with a spot denuded of chlorophyll-bodies by light present a singular appearance.

If this utricle be placed with the same spot (now denuded of chlorophyll) again exposed to intense light, in it also there follows the destruction of the contents of the cell, without any further decolorization of the chlorophyll bodies, just as before in the green utricles which were submitted to a longer action of the light, and, in fact, more quickly than in these.

This experiment therefore proves that the destruction of the contents of the green cells is independent of the chlorophyll colouring-matter, and shows (since the destruction occurs or does not occur in the gas-chamber under the same circumstances here also as in the green cells) that the destruction of protoplasm by light is also an act of combustion evoked by the heightened respiration in the light—or, in other words, that with the intensity of the light the affinity of oxygen for the combustible elements in the interior of the cell is increased. *But this experiment also shows that the chlorophyll, as long as it lasts, acts as a protective covering, moderating the injurious influence of light upon the protoplasm.*

Hence these experiments, by which is demonstrated the destructively heightened respiration of plants in intense light, at the same time bring to light the hitherto unimagined function of chlorophyll—by its strong absorption of the so-called chemical rays especially, *to limit the intensity of, and thus to regulate, the respiration.*

Now I have further taken the trouble to investigate which constituents of the plant-cell, being consumed in oxygen, are used up as the proper combustibles in the respiration of the cell. This question, too, had not yet been attacked. Investigation in intense light gives us the means of approaching it more closely.

Convincing evidence is easily obtained that all the better-known formal constituents of the cell-body, even in intense light, are incombustible and indestructible inside the cell. This holds true of the cell-wall, of the starch-grains, also of the amylaceous contents of the chlorophyll-bodies, and of the fatty matters (*i.e.* both those enclosed in the chlorophyll-bodies and the fat-globules occurring independently in the cell). Therefore none of these substances in the plant is directly utilized for the respiration. The cytoblast likewise, in the plant in intense light, appears incombustible; the changes which it undergoes I am inclined to regard as secondary effects of the alterations otherwise originated in the plasma in the light. On the other hand, in the protoplasm itself it is incontrovertible that alterations take place which prove themselves to be direct attacks of the oxygen-respiration taking place in light. It is especially remarkable that the *granules* within the contractile threads of protoplasm grow less and disappear. It can with equal distinctness be demonstrated that that envelope of the cell-body which I have named the cuticular layer * (Mohl's "primordial utricle") is diminished in mass, and that the granules (turned brown by iodine) which are so frequently imbedded in the cuticular layer become perceptibly fewer in number, so that, as it appears, hereby the most essential properties of the cuticular layer are changed.

Hence these bodies (of the chemical constitution of which we possess no further knowledge) preeminently represent the combustible material in the cell, which is expended in respiration. Respecting their nature perhaps an explanation may be given by the discovery (which I succeeded in making) of a previously unknown body in the plant-cell, which, of all the constituents it contains, may be designated as the most sensitive and the most perishable under the influence of light.

I ascertained, namely, that in the elementary substance of the chlorophyll-bodies, likewise in the elementary substance of the so-called amorphous chlorophyll in those plants which as yet possess no formed chlorophyll-bodies, and in every chlorophyll-green plant-cell without exception, there is present and distinguishable a peculiar body, on the preparation of

* 'Untersuchungen über den Bau und die Bildung der Pflanzenzelle.' Berlin, 1854.

which on a large scale, and the determination of its chemical properties, I am still engaged.

This body, which I call *hypochlorin* or *hypochromyl* (because it stands in the closest relation to the chlorophyll and constantly as it were occurs under it), can be with extreme facility brought into view by michrochemistry. In order to see it emerge, we have only to place any chlorophyll-green tissue (no matter from what section of phanerogams or cryptogams) for from twelve to twenty-four hours in diluted hydrochloric acid. The hypochlorin then makes its appearance in the form of extremely minute viscous drops which grow larger by accumulation, or masses of a semifluid consistence, which gradually become indistinctly crystalline scales or tufts, and finally grow out into indistinctly crystalline needles.

This body proves, from all its microchemical characters, to be an unctuous substance bathing the elementary substance of the chlorophyll-bodies, soluble in alcohol, ether, oil of turpentine, and benzole, insoluble in water and salt-solutions, and, after separation from the elementary substance, hardening in a shorter or longer space of time, perhaps through oxidation, into an obscurely crystalline body possessing all the properties of a resin or species of wax (in the sense of the older pharmacological chemistry). In their indistinctly developed forms, the needles formed by this substance remind one, in some measure, of the various shapes of bacilli of the bloom on the surface of the leaves in the Musaceæ and Gramineæ—for example, in *Heliconia farinosa* and the sugar-cane. From all these properties I have come to the opinion (with the reservation of a more exact chemical analysis which I contemplate making of it) that this body represents an ethereal oil which becomes resinous, if already in the ground-mass itself it does not form a mixture of several bodies of that kind (after the manner of the so-called balsams). But, apart from its more intimate chemical constitution, so much is certain, that this body, with its striking and easily demonstrable properties, is a constant and never-failing companion of the green colouring-matter in the ground-mass of the chlorophyll-bodies.

It is in fact never absent from any chlorophyll-green plant. It is more generally distributed in the chlorophyll-bodies than their starch and oily matters, and appears with them both in chlorophyll-bodies containing starch and in those which carry fat, and also in those containing both fat and starch. It is only those plants which possess no *proper green* chlorophyll (Phycochromaceæ, Diatomeæ, Fucaceæ, and Florideæ) that appear to exhibit a different behaviour; on this, however, my investigations are not yet concluded.

The universality of the occurrence of this body in all green chlorophyll-bearing plant-cells, its generation in light, its relation to oxygen, and its behaviour to the amylaceous contents of chlorophyll-bodies scarcely permit us to doubt that it is a true *primary* assimilation-product of green plants, from which, under the influence of light, are brought forth by oxidation the starch and oil enclosures of the chlorophyll-bodies as the reserve-substances destined to supply the elements for the circulation.

Hypochlorin, further, proves itself to be the most readily combustible, in light and oxygen, of all the constituents of the cell. It is consumed even sooner than chlorophyll by intense light in the presence of oxygen. For the ordinary intensities of light, under which the plant vegetates, chlorophyll affords sufficient protection to hypochlorin. With the heightened intensities in the experiments, that shelter no longer suffices, and even the light transmitted by the chlorophyll is intense enough for its rapid destruction in oxygen.

That hypochlorin, present in the normal conditions of the plant in variable amount in every grain of chlorophyll, is subjected to an uninterrupted increase and decrease can easily be shown ; and all comparative investigations between younger and older states of development of the chlorophyll-grains decidedly indicate that the accumulation and growth of starch in the ground-mass of chlorophyll-bodies advances hand in hand with a diminution of the hypochlorin in them. In darkness the hypochlorin (which, as it appears at least from my experiments hitherto, does not directly participate in the circulation of substance) is more stable than the starch—which again only shows that its transformation into more highly oxidized substances in the cell is accelerated by the heightened respiration in the light.

The facts here briefly sketched disclose a series of new points of view for judging of the action of light on plants. The demonstrable conditions under which the destruction of chlorophyll in the living plant is effected, the knowledge of the eminent augmentation of the amount of respiration with the increase of light-intensity (which may in every colour grow to such a degree as to destroy the cell), the undeniable influence exerted by the light-absorptions in the chlorophyll upon the amount of the respiration, finally the discovery of hypochlorin with its properties, conditions of origin, and behaviour in light, permit, if I am not mistaken, a more correct estimate of the hitherto misunderstood oldest and most general experiences on the relations between the gas-exchange of plants, light, and the function of chlorophyll.

I reserve the critical estimation of the bearing of the results here communicated of my observations upon the older statements and notions for the full description which is to appear in one of the next numbers of my 'Jahrbücher für wissenschaftliche Botanik,' where the necessary figures for illustration will be given. But I will here briefly epitomize the most important points of view for a preliminary elucidation.

I. As regards chlorophyll, the possibility of its destruction by light, in the living plant, is unequivocally demonstrated; but at the same time it is shown that the destruction is not a normal, but a pathological process. The plant cannot regenerate the destroyed colouring-matter; and the destruction itself is independent of the absorption of CO_2; hence it cannot play any part in the assimilation of carbon.

This overthrows every chemical theory that would indicate a genetic origin of the hydrates of carbon from chlorophyll.

It is further made evident that the destruction takes place in rays of all colours—in the red, yellow, green, and blue; and it is shown that no definite relation exists between the maxima of light-absorption in the chlorophyll colouring-matter and the colour which originates the destruction.

II. As regards *respiration*, not only is the proof produced (which, in full rigour, has hitherto been wanting) that the absorption of oxygen takes place also in direct sunlight—a proposition which strictly was previously only a theoretical postulate,—but it is at the same time shown that respiration is uncommonly heightened when the intensity of the light is increased. It is therefore a simple consequence, as also the directly proved result of my experiments, that the chlorophyll colouring-matter, by its strong absorption of light, lowers the amount of respiration, as it suspends the operation of the photochemically most operative portion of the radiation. Further the materials are discriminated which are used up in the respiration of the plant-cell; and a series of well-known form-constituents of it are shown to have no part in this.

III. For the deeper insight into the process of *assimilation*, by the proof of the presence in all chlorophyll-bodies of a previously unknown body, from which proceeds the starch enclosed in them, the universal primary product of assimilation of green plants is discovered. It is already, from the microchemical and morphological properties of this body, rendered in the highest degree probable that it is either a pure hydrocarbon, or else belongs to the series of organic plant-constituents which contain less oxygen than the so-called hydrates of carbon.

This, again, if the most probable hypothesis be admitted, that plants build up their first carbonaceous material out of carbonic acid and water, explains in a natural way why, notwithstanding the exceedingly heightened respiration in light, the volumes of the air-filled closed spaces in which plants are cultivated in sunlight may yet remain unaltered in magnitude.

IV. The *function of the green colour of vegetables* is reduced, in a way widely deviating from present notions, to its importance for the respiration of oxygen. It is shown that chlorophyll, as the regulator of the plant's respiration in light, by its strong absorption of the chemically most operative rays, depresses the amount of the respiration of green plants below that of their assimilation, and thus renders possible the accumulation of carbon-containing products and the existence of the plant in light.

This extinction of the blue rays in chlorophyll at the same time accounts for the observed greater efficiency of the rays of medium refrangibility for the evolution of the oxygen of the plant, as well as for the apparent coincidence of the assimilation-curve of the plant with the brightness-curve of the human eye. Unquestionably the maximum of assimilation for different plants lies in different parts of the effective rays of medium refrangibility, and depends on the amount of extinction (absolutely different for different plants) of the chemical rays in the chlorophyll.

Is this function of limiting the respiration the only one which chlorophyll exercises in the gas-exchange of plants? I shall return to this question in subsequent papers. It is indubitable that at present it is the only one actually demonstrated; for the sole support which, since the discovery of the giving-out of oxygen by plants, has hitherto always again and again been urged for the direct participation of chlorophyll in the process of decomposing carbonic acid, namely that only green parts liberate oxygen, finds in the lowering of the amount of the respiration by the chlorophyll its sufficient explanation.

V. In conclusion, it must be mentioned that for a series of plant-constituents belonging to the class of ethereal oils and their immediate derivates, and which it has been customary to explain as exclusively products of a retrograde metamorphosis, a universal immediate origin within the elementary substance of every chlorophyll-grain is demonstrated — a further following-out of which promises important elucidations respecting the distribution and occurrence of those bodies.

There is scarcely any phenomenon in the plant-world under the influence of light for the judging of which some new or essentially changed points of view are not gained through the theory here set up of the action of chlorophyll, and through the proof of the influence of light upon the respiration of plants. In the already mentioned memoir (in my 'Jahrbücher für wissenschaftliche Botanik'), with the preparation of which for the press I am now occupied, and which will bring into view the various forms of the hypochlorin needles, I hope to introduce some further details even in this direction.

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The study of fossil remains may be considered under different aspects—either in their biological relations, or in relation to the nature and succession of life in time, or as characteristic medals of different geological periods, or as explaining, from the known habits of closely-related forms, the conditions under which the various sedimentary formations were deposited. In whatever way we may wish to interpret them, a concise account of their nature and character is essential to the student of the life-history of the globe.

Few special treatises have been devoted to this subject, although notices of fossils occur in most geological text-books. The earlier works of Parkinson in 1811 and 1822, useful for their time, were twenty-two years later superseded by Mantell's 'Medals of Creation' (1844–54), which in its turn was followed (1860–61) by the more special work on Palæontology of Prof. Owen. Based upon the same principle as the latter work, the first edition of Prof. Nicholson's 'Manual of Palæontology' appeared in 1872, containing about 600 pages and 400 woodcuts.

With the exception of the omission of the last section, devoted to historical and stratigraphical geology, and which is, to some extent, embodied in the author's 'Ancient Life-History of the Earth,' in general arrangement the present edition is similar to the former; but it has been so thoroughly revised, greatly augmented, and largely rewritten, with the addition of nearly double the number of woodcuts, that it may be considered almost a new work, comprising a comprehensive account of the leading